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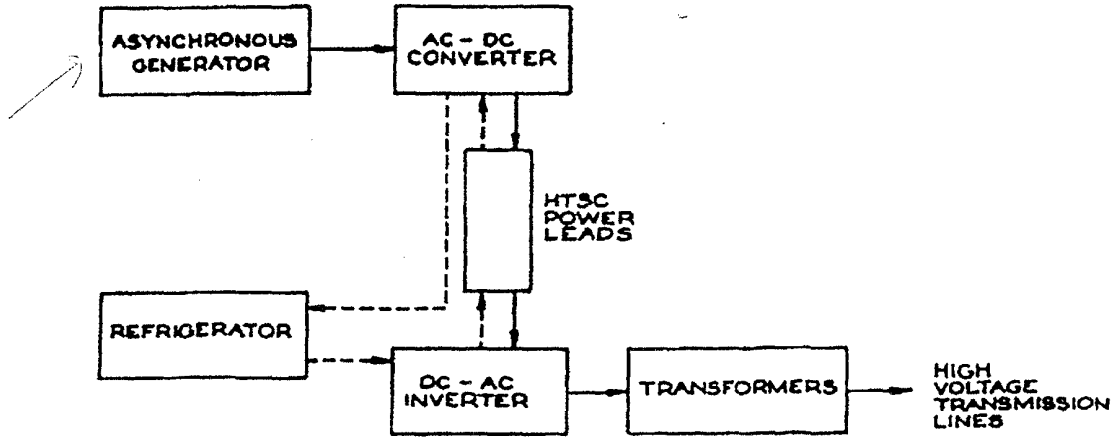
(54) Title: WIND TURBINES




(57) Abstract

A wind turbine comprises a tower, a wind driven propeller mounted at the top of the tower, an asynchronous generator at the top the tower to which the propeller is connected to drive the generator, and conductors formed of a high temperature superconducting mate to conduct the output from the generator at the top of the tower to the bottom of the tower. The turbine may comprise an AC-DC conve at the top of the tower to convert the output of the generator to DC and a DC-AC convertor at or near the base of the tower to convert DC power output of the turbine to AC at mains frequency.

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# WIND TURBINES

The present invention comprises a high efficiency wind turbine for generating electrical power.

## BACKGROUND

The utilisation of renewable energy resources is increasingly being pursued, driven by the depletion of fossil fuels and the perceived environmental damage associated with emissions from the use of these fuels. Wind energy is one of the most viable of the currently exploited renewable energy sources, and its utilisation is growing rapidly. It has the merit of being a distributed energy source with minimal environmental impact, but in many regions the economics of wind power are marginal especially if relatively cheap hydroelectricity is available.

Efficiency gains in wind turbines will enhance the competitiveness of this otherwise attractive resource. Beyond the issue of rotor design for maximal energy extraction, major inefficiencies reside in the gearbox and rotor blade feathering mechanisms required to ensure synchronous generation. Synchronous turbines comprise complex mechanisms and a gearbox to ensure constant generator speed and the turbines will shut down completely if the wind speed is too low or too high, over a broad range of intermediate conditions. These inefficiencies are very obvious when viewing a wind farm under variable conditions. A significant fraction of turbines have no rotation as they hunt for appropriate wind direction and speed.

## SUMMARY OF INVENTION

In broad terms the invention comprises a wind turbine comprising a tower, a wind driven propeller mounted at the top of the tower, an asynchronous generator at the top of the tower to which the propeller is connected to drive the generator, and conductors formed of a high temperature superconducting (HTSC) material to conduct the output from the generator at the top of the tower to the bottom of the tower.

Preferably the wind turbine comprises an AC-DC converter at the top of the tower to convert the output of the generator to DC.

Preferably the HTSC conductors connect to a DC-AC convertor at or near the base of the tower to convert the DC power output of the turbine to AC.

By high temperature superconducting (HTSC) material is meant a superconducting cuprate, such as $YBa_2Cu_3O_{7-\delta}$ or $(Bi,Pb)_2Sr_2Ca_2Cu_3O_{10-\delta}$, or any other suitable HTSC material preferably with transition temperature, $T_c$ greater than the temperature of liquid nitrogen, 77K.

In conventional wind turbines copper leads of large cross-sectional area are used and the weight of copper in each lead may be up to 3 tonnes. Typically the output voltage may be of the order of 400V and so for a 1.5 MW turbine currents as large as 4000 Amps must be transmitted in power leads down the tower which may be up to 100 metres in height. In spite of the use of such huge power leads (and their associated large capital cost) losses in the tower may still be of the order of 5-7%. The combined capital cost and lost generation revenue over the turbine lifetime may be a large

fraction of the total initial turbine capital cost. As well as having substantially increased generation efficiency, the invention also allows a lighter, more compact installation in the tower, reducing the structural requirements of the tower and foundation.

The AC power generated in the asynchronous generator has variable frequency depending upon wind velocity. However the turbine operates over a broader range of wind conditions and gearbox losses are eliminated.

## BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be further described with reference to the accompanying drawings, which show a preferred form of the invention by way of example. In the drawings:

Figure 1 shows a typical wind turbine,

Figure 2 is a schematic block diagram of the electrical systems of a wind turbine of the invention, and

Figure 3 is the same schematic block diagram as Figure 2 but also showing a refrigerator to pump a cryogen such as liquid nitrogen through the HTSC leads.

## DETAILED DESCRIPTION OF PREFERRED FORM

Figure 1 shows a typical wind turbine, comprising a tower 1, a housing 2 rotatably mounted at the top of the tower and which houses a generator which is driven by a propeller 3. In a conventional synchronous turbine, the housing 2 also contains a gear box and rotor blade feathering mechanisms required to ensure synchronous generation. In turbines of the invention a feathering mechanism may be required but only arranged to operate at very high wind speeds outside of the normal range of operation to physically protect the wind turbine.

Referring to Figure 2, an asynchronous generator is mounted in the housing 2 of the turbine, which is driven by the propeller 3. In the preferred form AC-DC converter is also contained within the housing 2, to convert variable frequency AC power from the asynchronous generator to low voltage high current DC. High temperature superconductor (HTSC) power leads run from the asynchronous generator in the housing 2, and down within the interior of the tower 1 to the base of the tower.

A DC-AC converter is provided at or near the base of the tower to which the HTSC power leads connect. The DC-AC converter is arranged to convert the low voltage high current power to a synchronous AC output at mains frequency, such as 50 Hz for example.

The output of the DC-AC converter may be fed to a step-up transformer to convert the synchronous AC output to high voltage low current output for connection to a conventional high voltage power grid or similar. In a wind farm consisting of a number of turbines, the HTSC power leads may continue from the base of the turbine to

conduct the output from the turbine to a central station to which the outputs of other wind turbines are also supplied, where the DC outputs are combined and converted to synchronous AC, and connected to a power grid.

Figure 3 also shows a refrigerator which is arranged to pump a cryogen such as liquid nitrogen through cooling pathways in the HTSC power leads to maintain the HTSC material at a temperature at which the HTSC leads conduct without resistance (superconductivity), and back again to recycle through the refrigerator. Preferably MOSFETS are used in the power inverter and the cryogen is also circulated in a common circuit through the AC-DC and DC-AC converters to cool these components which can result in an up to 30-fold reduction in the on-resistance. Superconducting inductors are also preferably used to further greatly increase electrical efficiency in the power electronics. An integrated refrigeration system circulates the cryogen refrigerant through the HTSC power leads and the power electronics systems as indicated in Figure 3, for maximum efficiency.

The low voltage winding of the high voltage step-up transformer may also be wound using superconducting wires, or both low and high voltage windings may be wound using superconducting wires to obtain further efficiencies.

In an alternative arrangement DC power from the superconducting power leads at the base of the tower, or beyond, may be switched from the load or transmission lines to a storage device such as a battery, fuel cell or other electrolytic cell to allow for storage when demand falls below generation capacity.

The foregoing describes the invention including a preferred form thereof. Alterations and modifications as will be obvious to those skilled in the art are intended to be incorporated within the scope hereof, as defined in the accompanying claims.

CLAIMS

1. A wind turbine comprising a tower, a wind driven propeller mounted at the top of the tower, an asynchronous generator at the top of the tower to which the propeller is connected to drive the generator, and conductors formed of a high temperature superconducting material (HTSC) to conduct the output from the generator at the top of the tower to the bottom of the tower.

2. A wind turbine according to claim 1 comprising an AC-DC convertor at the top of the tower to convert the output of the generator to DC.

3. A wind turbine according to claim 2 wherein the HTSC conductors connect to a DC-AC convertor at or near the base of the tower to convert the DC power output of the turbine to AC.

4. A wind turbine according to claim 3 wherein the output of the DC-AC convertor is connected to a step-up transformer to convert the output to a high voltage low current power for transmission over power transmission lines.

5. A wind turbine according to any one of claims 1 to 4 incorporating a refrigeration system arranged to pump a cryogen through the HTSC conductors.

6. A wind turbine according to claim 3 incorporating a refrigeration system arranged to pump a cryogen through the HTSC conductors and power electronics components in the AC-DC converter at the top of the tower and optionally the DC-AC convertor at the base of the tower.

7. A wind farm comprising a number of wind turbines as claimed in any one of the preceding claims connected in parallel, and wherein the HTSC conductors from each turbine connect the turbines to a central station.

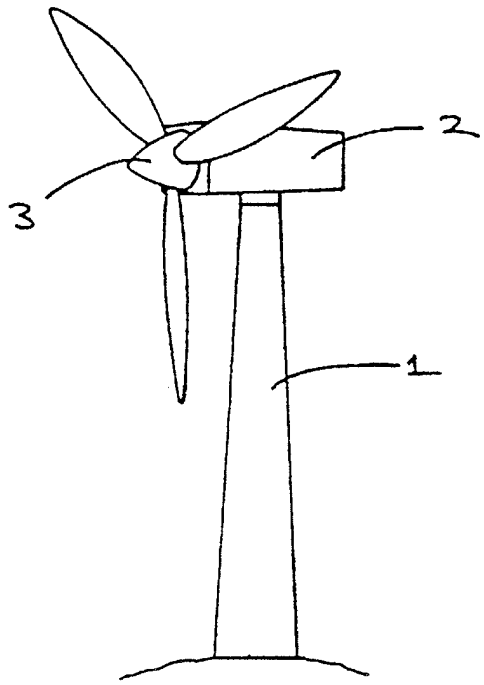


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Figure 1

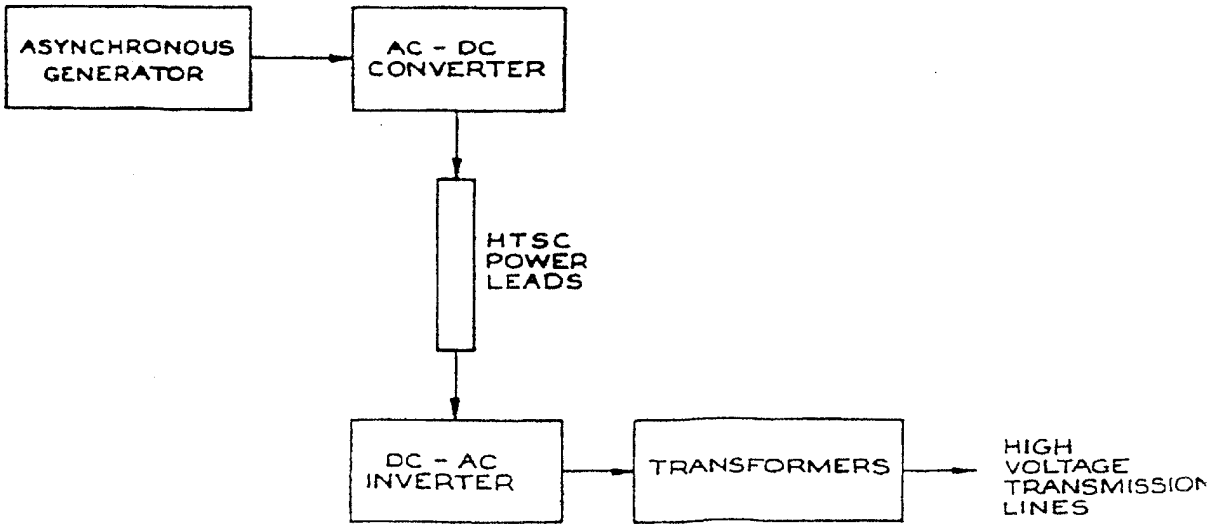


Figure 2

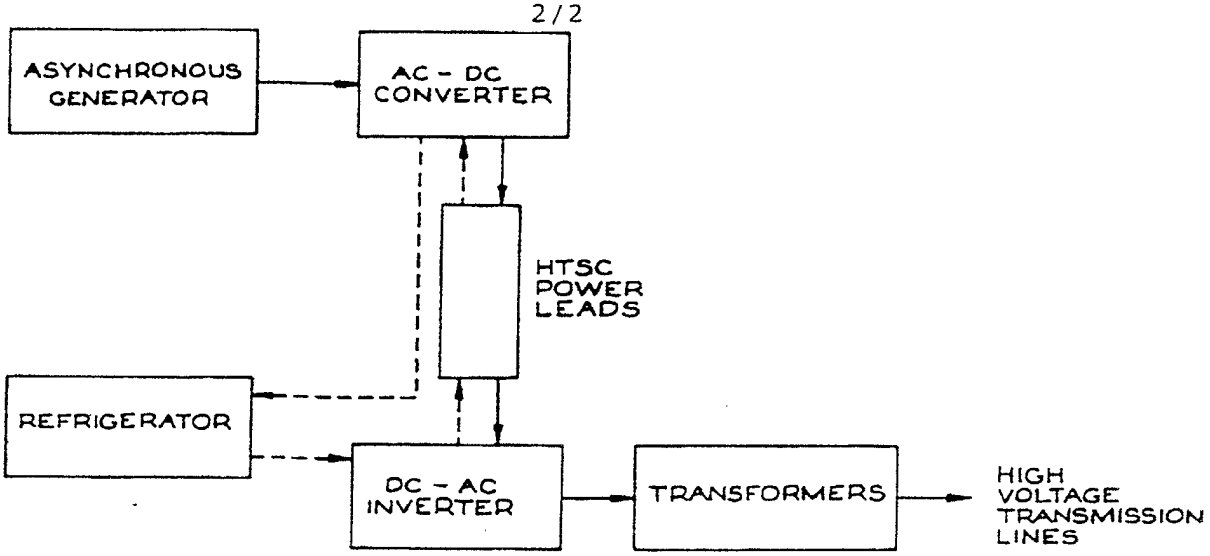
ASYNCHRONOUS GENERATOR
AC - DC CONVERTER
HTSC POWER LEADS
REFRIGERATOR
DC - AC INVERTER
TRANSFORMERS
HIGH VOLTAGE TRANSMISSION LINES

Figure 3

# INTERNATIONAL SEARCH REPORT

International Application No.
PCT/NZ 97/00065

**A. CLASSIFICATION OF SUBJECT MATTER**

Int Cl[6]: F03D 9/00, H02M 5/45

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)
F03D 9/00, 9/02, 11/00, H02K 7/18 (1975 onwards)

Documentation searched other than minumum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
DERWENT (SUPERCONDUCT:)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| Y | US 5315159 A (GRIBNAU) 24 May 1994<br>abstract | 1-7 |
| Y | AU 22801/88 A (IMPERIAL CHEMICAL INDUSTRIES) 6 April 1989<br>page 1A, lines 8-34 | 1-7 |
| A | Derwent Abstracts Accession No 92-431396/52, Class Q55, SU 1710824 A (UNIV DNEPR) 7 February 1992<br>abstract | |

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|---|---|---|---|---|---|---|---|
| US | 5315159 | AU | 65487/90 | EP | 495872 | NL | 8902534 |
| | | US | 5315159 | WO | 9105953 | | |
| AU | 22801/88 | NO | 884229 | EP | 531218 | FR | 2681076 |
| | | NZ | 244244 | US | 5446138 | WO | 9528234 |
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